UNIT # 2
KINEMATICS

Q1. Define kinematics?

Ans: Kinematics:

Kinematics is the study of motion of an object without discussing the cause of motion.

Q2. Differentiate between rest and motion?

Ans: Difference between rest and motion:

Rest:

A body is said to be at rest, if it does not change its position with respect to its surroundings.

Motion:

A body is said to be in motion, if it changes its position with respect to its surroundings.

The state of rest or motion of a body is relative. For example, a passenger sitting in a moving bus is at rest because he/she is not changing his/her position with respect to other passengers or objects in the bus. But to an observer outside the bus, the passengers and the objects inside the bus are in motion.

Q3. Define surroundings.

Ans: Surroundings:

Surroundings are the places in its neighbourhood where various objects are present. Similarly,

Q4. List the types of motion?

Ans: Types of motion:

There are three types of motion.

(i) Translatory motion (linear, random and circular)

(ii) Rotatory motion

(iii) Vibratory motion (to and fro motion)

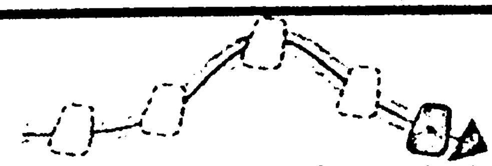
Q5. Describe translatory motion with the help of examples?

Ans: Translatory motion:

In translational motion, a body moves along a line without any rotation. The line may be straight or curved

Examples:

Riders moving in a Ferris wheel are also in translational motion. Their motion is in a circle without rotation.



Translatory motion of an object along a curved path.

Q6. Describe the different types of translatory motion?

Ans: Types of translatory motion:

Translatory motions can be divided into linear motion, circular motion and random motion.

i. Linear motion:

Straight line motion of a body is knows as its linear motion.

Examples:

The motion of objects such as a car moving on a straight and level road is linear motion.

Aeroplanes flying straight in air and objects falling vertically down are also the examples of linear motion.

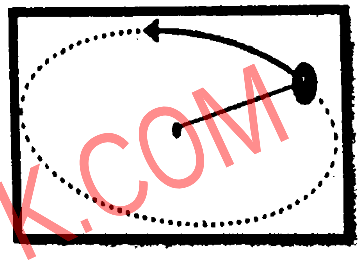
ii. Circular motion:

The motion of an object in a circular path is known as circular motion

Examples:

A stone tied at the end of a string can be made to whirl. The stone moves in a circle and thus has circular motion.

A toy train moving on a circular track. A bicycle or a car moving along a circular track possesses circular motion. Motion of the Earth around the Sun and motion of the moon around the Earth are also the examples of circular motions.



iii. Random motion:

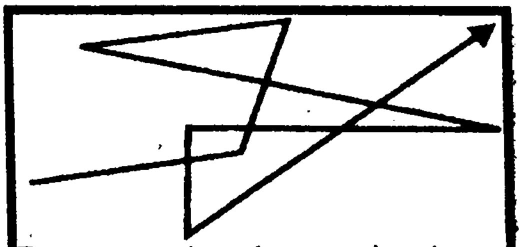
The disordered or irregular motion of an object is called random motion.

Examples:

The motion of insects and birds are irregular. Thus, motion of insects and birds is random motion.

The motion of dust or smoke particles in the air is also random motion.

The Brownian motion of a gas or liquid molecules along a zig-zag path is also an example of random motion.



Random motion of gas molecules is called Brownian motion

Q7. Describe rotatory motion with the help of examples?

Ans: Rotatory motion:

The spinning motion of a body about its axis is called its rotatory motion.

Examples:

The top spins about its axis passing through it and thus it possesses rotatory motion. An axis is a line around which a body rotates. In circular motion, the point about which a body goes around, is outside the body. In rotatory motion, the line, around which a body moves about, is passing through the body itself.

The motion of a wheel about its axis and that of a steering wheel are the examples of rotatory motion. The motion of the Earth around the Sun is circular motion and not the spinning motion. However, the motion of the Earth about its geographic axis that causes day and night is rotatory motion.

Q8. Can you point out some differences in circular and rotatory motion?

Ans: Difference between circular and rotatory motion:

Any turning as if on an axis is rotary motion. Any rotary motion where the radius of gyration length and axis of rotation are fixed is circular motion. And that's the difference. Circular motion is just a special case of rotary motion. That is, there is no fixed axis and radius restriction for rotary motion, but there is for circular motion.

For example, all planets have rotary motion around their suns. But most of the orbits are elliptical; so the rotation axes (there are two in an ellipse) and radii of gyration vary as they trek around. So most, if not all, planets do not have circular motion.

Note:

Gyration length:

A length that represents the distance in a rotating system between the point about which it is rotating and the point to or from which a transfer of energy has the maximum effect.

Mini Exercise

1. When a body is said to be at rest?

Ans: A body is said to be at rest, if it does not change its position with respect to its surroundings.

2. Give an example of a body that is at rest and is in motion at the same time.

Ans: Motion and rest are relative concepts. There is no absolute rest. We can define the state of rest or motion only with respect to another object or a point in space taken as reference.

Examples:

i. A person inside a train considers himself to be at rest with respect to the fellow passengers or the walls of the train. But when he looks outside, he finds himself to be in motion with respect to the trees outside.

ii. A passenger sitting in a moving bus is at rest because he/she is not changing his/her position with respect to other passengers or objects inside the bus. But to an observer outside the bus, the passengers and the objects inside the bus are in motion.

3. Mention the type of motion in each of the following:

(i) A ball moving vertically upward.

Ans: Linear motion.

(ii) A child moving down a slide.

Ans: Linear motion.

(iii) Movement of a player in a football ground.

Ans: Random motion.

(iv) The flight of a butterfly.

Ans: Random motion.

(v) An athlete running in a circular track.

Ans: Circular motion.

(vi) The motion of a wheel.

Ans: Circular motion.

(vii) The motion of a cradle.

Ans: Vibratory motion.

Q9. Describe vibratory motion with the help of examples?

Ans: Vibratory motion:

To and fro motion of a body about its mean position is known as vibratory motion.

Examples:

Consider the motion of a baby in a swing. As it is pushed, the swing moves back and forth about its mean position. The motion of the baby repeats from one extreme to the other extreme with the swing. Such type of motion is called vibratory motion.

To and fro motion of the pendulum of a clock about its mean position, it is called vibratory motion.

A baby in a cradle moving to and fro, to and fro motion of the hammer of a ringing electric bell and the motion of the string of a sitar are some of the examples of vibratory motion.

Q10. Differentiate between scalars and vectors?

Ans: Difference between Scalars and vectors:

Scalars	Vectors
A scalar quantity is described completely by its magnitude only.	A vector quantity is described completely by magnitude and direction.
Examples: Examples of scalars are mass, length, time, speed, volume, work, energy, density, power, electric charge, pressure, area, temperature,	**Examples:** Examples of vectors are velocity, displacement, force, momentum, torque, weight, electric potential, etc.

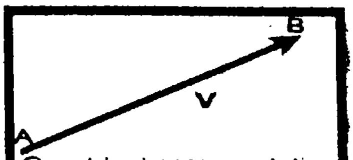
Q11. How can vector quantities be represented graphically?

Ans: Representation of vectors (Symbolic representation of a vector):

To differentiate a vector from a scalar quantity, we generally use bold letters to represent vector quantities, such as **F, a, d** or a bar or arrow over their symbols such as $\bar{F}$, $\bar{a}$, $\bar{d}$ or $\vec{F}$, $\vec{a}$ and $\vec{d}$.

Vector representation/Graphical representation of a vector:

A straight line is drawn with an arrow head at one end. The length of the line, according to some suitable scale, represents the magnitude and the arrow head gives the direction of the vector.



Graphical representation of a vector V

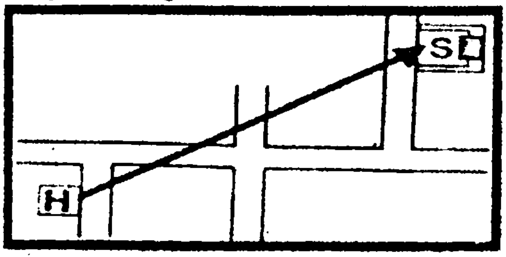
Q12. Define the term position?

Ans: Position:

The term position describes the location of a place or a point with respect to some reference point called origin.

For example:

You want to describe the position of your school from your home. Let the school be represented by S and home by H. The position of your school from your home will be represented by a straight line HS in the direction from H to S.

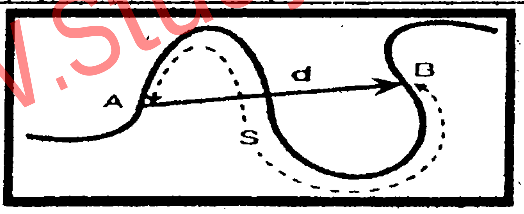


Position of the school S from the home H.

Q13. Explain the difference between distance and displacement?

Ans: Difference between distance and displacement:

Distance	Displacement
i. Length of a path between two points is called the distance between those points.	**i.** Displacement is the shortest distance between two points which has magnitude and direction.
ii. Distance is a scalar quantity.	**ii.** Displacement is a vector quantity.
iii. Distance is denoted by "S". $S = vt$ Its SI unit is metre (m).	**iii.** Displacement is denoted by "**d**". $\mathbf{d} = vt$ Its SI unit is metre (m).



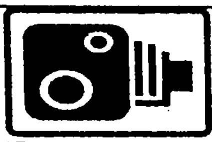
Distance S (dotted line) and displacement **d** (dark line) from points A to B.

Q14. What is the difference between speed and velocity?

Ans: Difference between speed and velocity:

Speed	Velocity
i. The distance covered an object in unit time is by called its speed. $Speed = \frac{distance\ covered}{time\ taken}$ $Distance = speed \times time$ or $S = vt$	**i.** The rate of displacement of a body is called its velocity. $Velocity = \frac{displacement}{time\ taken}$ $v = \frac{d}{t}$ or $d = vt$
ii. Speed is a scalar quantity.	**ii.** Velocity is a vector quantity.
iii. SI unit of speed is metre per second (ms^{-1}).	**iii.** SI unit of velocity is the same as speed i.e., metre per second (ms^{-1}).

DO YOU KNOW?

Which is the fastest animal on the earth? Falcon can fly at a speed of 200 kmh^{-1} 	Cheetah can run at a speed of 70kmh^{-1} 
 Speed Cameras Special Feature A LIDAR gun is light detection and ranging speed gun. It uses the time taken by laser pulse to make a series of measurements of a vehicle's distance from the gun. The data is then used to calculate the vehicle's speed.	 A paratrooper attains a uniform velocity called terminal velocity with which it comes to ground.

Q15. Define uniform speed.

Ans: Uniform speed:

A body has uniform speed if it covers equal distances in equal intervals of time however short the interval may be.

Q16. Define variable speed.

Ans: Variable speed:

If a body covers unequal distances in equal interval of time, however small the intervals may be, the speed of the body is said to be variable.

Q17. Define average speed?

Ans: Average speed:

The ratio between distance and total time taken is known as average speed

$$Average\ Speed = \frac{Total\ distance\ covered}{Total\ time\ taken}$$

$$V_{av} = \frac{s}{t}$$

Q18. Define uniform velocity?

Ans: Uniform velocity:

A body has uniform velocity if it covers equal displacement in equal intervals of time however short the interval may be.

Q19. Define variable velocity?

Ans: Variable velocity:

If speed or direction changes with time then the velocity of such a body is said to be variable.

Q20. Define average velocity?

Ans: Average velocity:

The ratio between displacement and time is known as average velocity.

$$Average\ velocity = \frac{Distance}{Time}$$

$$V_{av} = \frac{d}{t}$$

Q21. Define acceleration?

Ans: Acceleration:

Acceleration is defined as the rate of change of velocity of a body.

$$Acceleration = \frac{change\ in\ velocity}{time\ taken}$$

$$Acceleration = \frac{final\ velocity - initial\ velocity}{time\ taken}$$

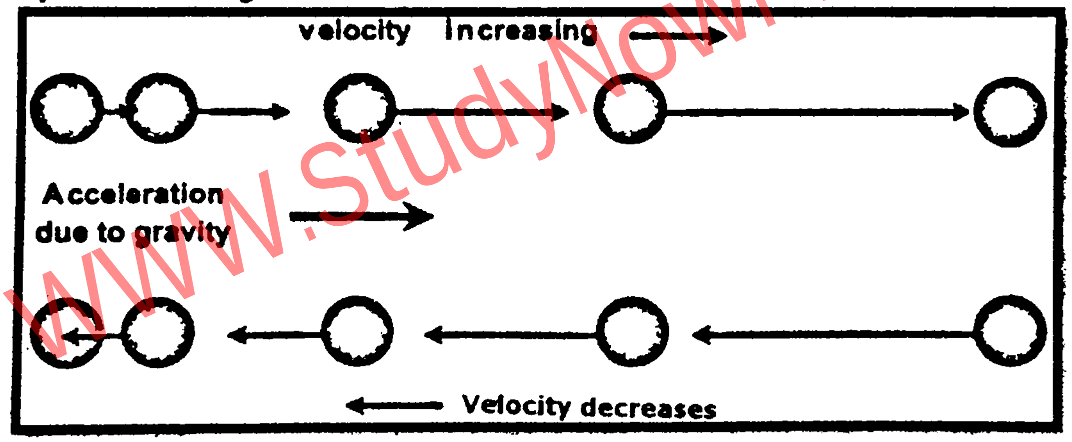
$$a = \frac{V_f - V_i}{t}$$

Unit of acceleration:

SI unit of acceleration is metre per second per second (ms^{-2}).

USEFUL INFORMATION

Acceleration of a moving object is in the direction of velocity if its velocity is increasing. Acceleration of the object is opposite to the direction of velocity if its velocity is decreasing.



Q22. Define uniform acceleration?

Ans: Uniform acceleration:

A body has uniform acceleration if it has equal changes in velocity in equal intervals of time however short the interval may be.

Q23. Differentiate between positive and negative acceleration?

Ans: Positive acceleration:

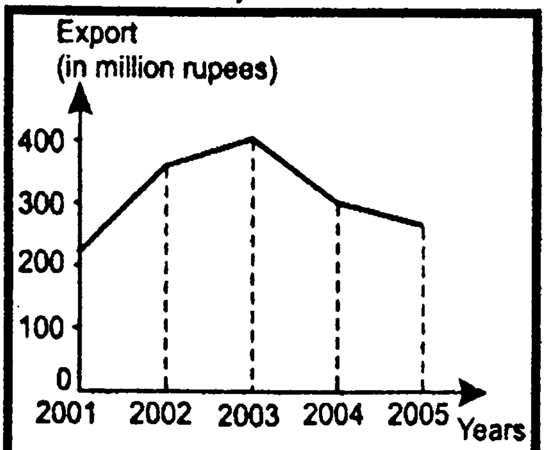
Acceleration of a body is positive if its velocity increases with time. The direction of this acceleration is the same in which the body is moving without change in its direction.

Negative acceleration/Deceleration or retardation:

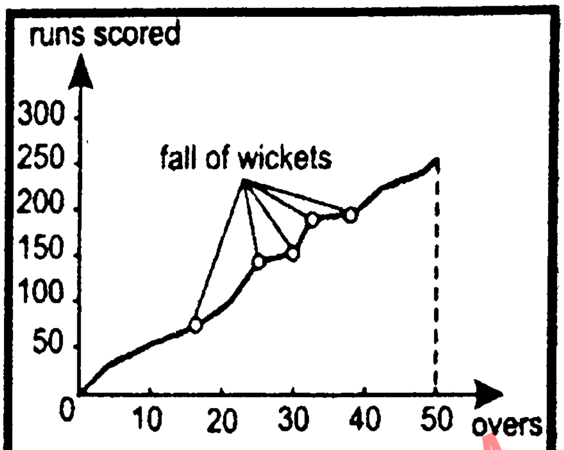
Acceleration of a body is negative if velocity of the body decreases. The direction of negative acceleration is opposite to the direction in which the body is moving. Negative acceleration is also called deceleration or retardation.

DO YOU KNOW?

A graph may also be used in everyday life such as to show year-wise growth/decline of export, month-wise rainfall, a patient's temperature record or runs per over scored by a team and so on.



Export of rice from 2001-2005



Runs scored by a cricket team.

Q24. What do you mean by graph, variables, independent quantity and dependent quantity?

Ans: Graph:

Graph is a pictorial way of presenting information about the relation between various quantities.

Variables:

The quantities between which a graph is plotted are called the variables.

Independent quantity:

One of the quantities is called the independent quantity.

Dependent quantity:

The value of which varies with the independent quantity is called the dependent quantity.

Q25. What is the purpose of distance-time graph? How it is plotted?

Ans: Distance-time graph:

It is useful to represent the motion of objects using graphs. The terms distance and displacement are used interchangeably when the motion is in a straight line. Similarly if the motion is in a straight line then speed and velocity are also used interchangeably.

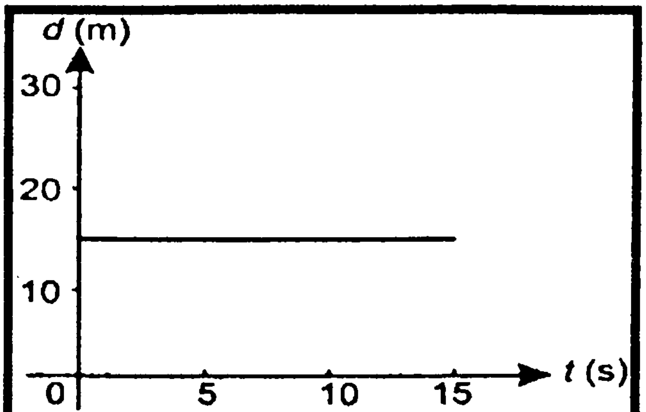
Note:

In a distance-time graph, time is taken along horizontal axis while vertical axis shows the distance covered by the object.

Q26. Sketch a distance-time graph for a body at rest. How will you determine the speed of a body from this graph?

Ans: Object at rest:

In the graph shown in figure, the distance moved by the object with time is zero. That is, the object is at rest. Thus a horizontal line parallel to time axis on a distance-time graph shows that speed of the object is zero.



Distance-time graph when the object is at rest

Q27. Plot and interpret a distance-time graph for a body moving with constant speed?

Ans: Object moving with constant speed:

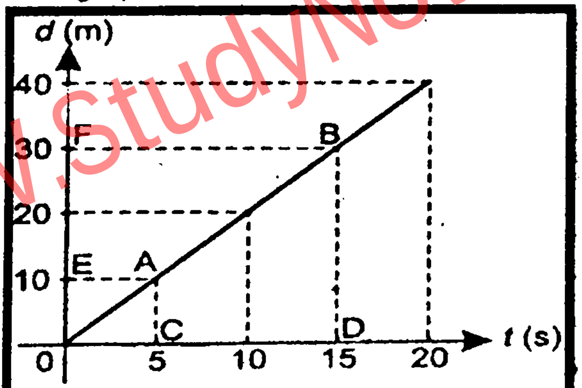
The speed of an object is said to be constant if it covers equal distances in equal intervals of time. The distance-time graph as shown in figure is a straight line. Its slope gives the speed of the object.

Consider two points A and B on the graph.

$$\text{speed of the object} = \text{Slope of line AB}$$

$$= \frac{\text{distance EF}}{\text{time CD}} = \frac{20\,m}{10\,s} = 2\,\text{ms}^{-1}$$

The speed found from the graph is $2\,ms^{-1}$.



Distance-time graph showing constant speed

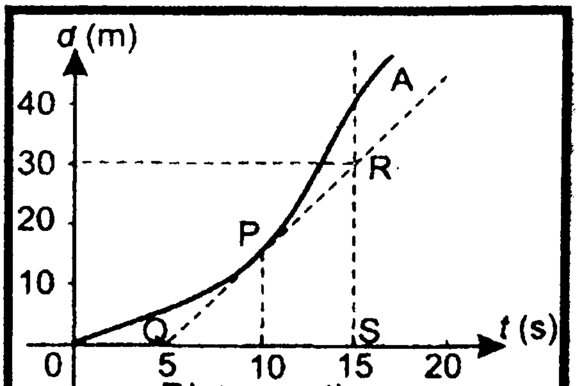
Q28. Sketch a distance-time graph for a body moving with variable speed?

Ans: Object moving with variable speed:

When an object does not cover equal distances in equal intervals of time then its speed is not constant. In this case the distance-time graph is not a straight line as shown in figure. The slope of the curve at any point can be found from the slope of the tangent at that point. For example,

$$Slope\ of\ tangent\ at\ P = \frac{RS}{QS} = \frac{30\,m}{10\,s} = 3\,ms^{-1}$$

Thus, speed of the object at P is $3\,ms^{-1}$.



Distance-time graph showing variable speed.

Note:

The speed is higher at instants when slope is greater; speed is zero at instants when slope is horizontal.

Q29. What do you mean by speed-time graph?

Ans: Speed-time graph:

In a speed-time graph, time is taken along x-axis and speed is taken along y-axis.

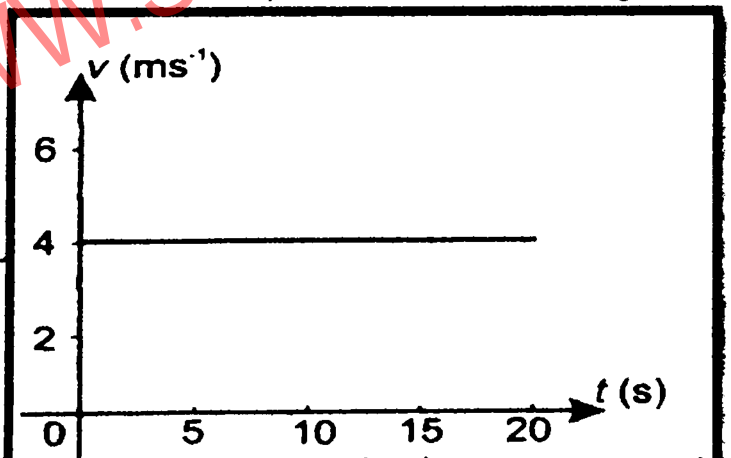
Q30. Sketch a speed-time graph for a body moving with constant speed?

OR

Q31. What would be the shape of a speed - time graph of a body moving with constant speed?

Ans: Object moving with constant speed:

When the speed of an object is constant ($4\ ms^{-1}$) with time, then the speed-time graph will be a horizontal line parallel to time-axis along x-axis.



Speed-time graph showing constant speed

A straight line parallel to time axis represents constant speed of the object.

Q32. Sketch a speed-time graph for a body moving with uniformly changing speed?

OR

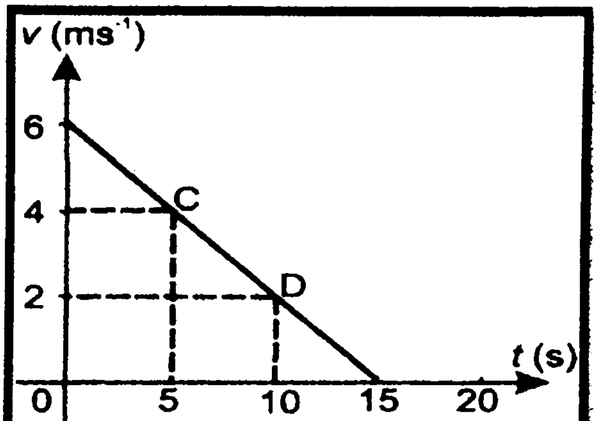
What would be the shape of a speed - time graph of a body moving with uniformly changing speed?

Ans: Object moving with uniformly changing speed (uniform acceleration):

Let the speed of an object be changing uniformly. In such a case speed is changing at constant rate. Thus its speed-time graph would be a straight line such.

A straight line means that the object is moving with uniform acceleration. Slope of the line gives the magnitude of its acceleration.

Speed-time graph gives negative slope. Thus, the object has deceleration of 0.4 ms^{-2}.



Graph of an object moving with uniform deceleration

Q33. Sketch a speed-time graph for distance travel by a moving object?

OR

What would be the shape of a speed - time graph for distance travel by a moving object?

Ans: Distance travelled by a moving object:

The area under a speed-time graph represents the distance travelled by the object. If the motion is uniform then the area can be calculated using appropriate formula for geometrical shapes represented by the graph.

Q34. Describe the purpose of different equations of motion?

Ans: Equations of motion:

There are three basic equations of motion for bodies moving with uniform acceleration. These equations relate initial velocity, final velocity, acceleration, time and distance covered by a moving body.

Q35. Derive the first equation of motion for uniformly accelerated rectilinear motion.

OR

Which equation of motion establishes the relationship between v_f, v_i, a and t, drive relation between these quantities.

OR

Prove that $v_f = v_i + at$.

OR

Derive equation of motion which is independent of distance S.

Ans: Suppose a body is moving with initial velocity v_i, and after time t its velocity becomes v_f. Then acceleration a is given by

$$a = \frac{v_f - v_i}{t}$$

or $V_f - V_i = at$

$V_f = V_i + at$

Second Method (Graphical method):

First equation of motion:

Speed-time graph for the motion of a body is shown in figure. Slope of line AB gives the acceleration a of a body.

$$\text{slope of line AB} = a = \frac{AB}{Ac} = \frac{BD - CD}{OD}$$

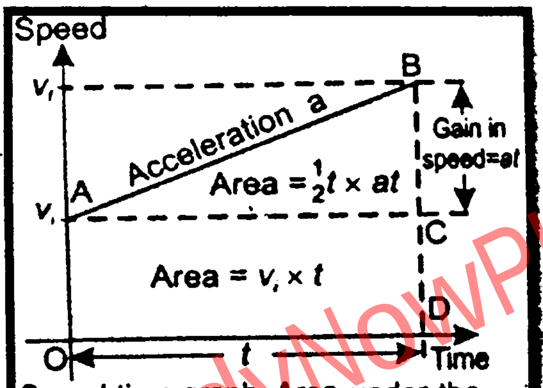
as

$BD = V_f,\ CD = V_i$ and $OD = t$

Hence $a = \frac{V_f - V_i}{t}$

or $V_f - V_i = at$

$V_f = V_i + at$



Speed-time graph. Area under the graph gives the distance covered by body

Q36. Derive the second equation of motion for uniformly accelerated rectilinear motion.

OR

Which equation of motion establishes the relationship between S, a, v_i and v_f?

OR

Derive the equation of motion which is independent of t.

OR

Derive the second equation of motion?

OR

Prove that $S = v_i t + \frac{1}{2}at^2$

Ans: Suppose a body is moving with initial velocity v_i and after a certain time t its velocity becomes v_f then the total distance S covered in time t, is given by

$S = v_{av} \times t$

$S = \left(\frac{v_f + v_i}{2}\right) \times t$ ....(i)

From first equation of motion. $v_f = v_i + at$

Putting the value of v_f in equation (i).

$$S = \left(\frac{v_i + at + v_i}{2}\right) \times t$$

$$S = \left(\frac{2V_i + at}{2}\right) \times t$$
$$S = \frac{2V_it + at^2}{2}$$
$$S = \frac{2V_it}{2} + \frac{at^2}{2}$$
$$S = V_it + \frac{1}{2}at^2$$

Second Method (Graphical method):

Second equation of motion:

In speed-time graph shown in figure, the total distance S travelled by the body is equal to the total area OABD under the graph. That is

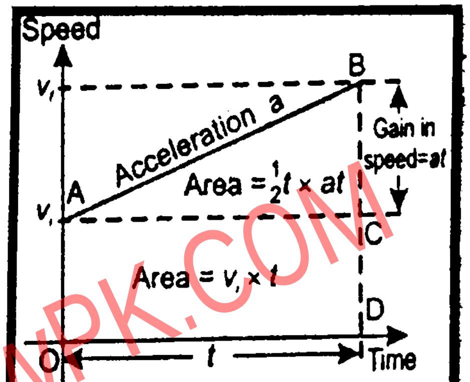
Total distance S = area of (rectangle OACD + triangle ABC)

Area of rectangle OACD $= OA \times OD$

$= V_i \times t$

Area of triangle ABC $= \frac{1}{2}(AC \times BC)$

$= \frac{1}{2}t \times at$



Speed-time graph. Area under the graph gives the distance covered by body

Since Total area OABD = area of rectangle OACD + area of triangle ABC

Putting values in the above equation, we get

$$S = V_it + \frac{1}{2}t \times at$$
$$S = V_it + \frac{1}{2}at^2$$

Q37. Derive the third equation of motion for uniformly accelerated rectilinear motion.

OR

Which equation of motion establishes the relationship between S, a, v_i and v_f?

OR

Derive the equation of motion which is independent of t.

OR

Derive the Third equation of motion?

OR

Prove that $2aS = v_f^2 - v_i^2$

Ans: Suppose a body is moving with initial velocity v_i, and after a certain time t its velocity becomes v_f, then the distance S covered by it is given by

$S = v_{av} \times t$

$S = \left(\frac{V_f + V_i}{2}\right) \times t$ ....(i)

From first equation of motion find the value of t.

$v_f = v_i + at$ or $t = \frac{V_f - V_i}{a}$

Putting this value of t in equation (i).

$$S = \left(\frac{V_f + V_i}{2}\right) \times \left(\frac{V_f - V_i}{a}\right)$$

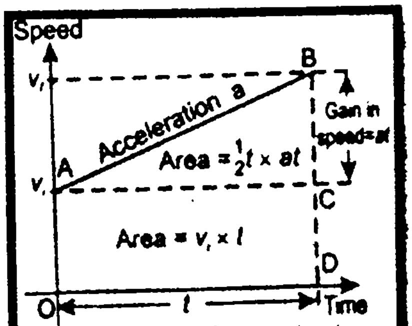
$2aS = (v_f + v_i) \times (v_f - v_i)$ by using formula $(a + b)(a - b) = a^2 - b^2$

$2aS = v_f^{\,2} - v_i^{\,2}$.

Second Method (Graphical method):

Third equation of motion:

In speed-time graph shown in figure, the total distance S travelled by the body is given by the total area OABD under the graph.



Speed-time graph. Area under the graph gives the distance covered by body

Total area OABD = $S = \frac{OA + BD}{2} \times OD$

or $2S = (OA + BD) \times OD$

Multiply both sides by $\frac{BC}{OD}$, we get: $(\because \frac{BC}{OD} = a)$

$$2S \times \frac{BC}{OD} = (OA + BD) \times OD \times \frac{BC}{OD}$$

$$2S \times \frac{BC}{OD} = (OA + BD) \times BC \quad \ldots\ldots\ldots (i)$$

Putting the values in the above equation (i), we get

$$2S \times a = (V_i + V_f) \times (V_f - V_i)$$

$$2as = V_f^{\,2} - V_i^{\,2}$$

USEFUL INFORMATION

- **To convert ms^{-1} to kmh^{-1}**

  $1\ ms^{-1} = 0.001\ km \times 3600\ h^{-1} = 3.6\ kmh^{-1}$

  Thus multiply speed in ms^{-1} by 3.6 to get speed in kmh^{-1} e.g.,

  $20\ ms^{-1} = 20 \times 3.6\ kmh^{-1} = 72\ kmh^{-1}$

- **To convert kmh^{-1} to ms^{-1}**

  $1\ kmh^{-1} = \frac{1000\ m}{60 \times 60\ s} = \frac{10}{36}\ ms^{-1}$

  Thus multiply speed in kmh^{-1} by $\frac{10}{36}$ to get speed in ms^{-1} e.g.,

  $50\ kmh^{-1} = 50 \times \frac{10}{36}\ ms^{-1} = 13.88\ ms^{-1}$

  Similarly

- **To convert ms^{-2} to kmh^{-2}**

  Multiply acceleration in ms^{-2} by $\frac{3600 \times 3600}{1000} = 12960$ to get its value in kmh^{-2}.

- **To convert kmh^{-2} to ms^{-2}**

  Divide acceleration in kmh^{-2} by 12960 to get its value in ms^{-2}.

Q38. Drop an object from some height and observe its motion. Does its velocity increase, decrease or remain constant as it approaches the ground?

Ans: Velocity of an object will increases due to earth gravity. That is why for bodies falling down freely g is positive.

Q39. Explain motion of freely falling bodies?

Ans: Motion of freely falling bodies:

The acceleration of freely falling bodies is called **gravitational acceleration**. It is denoted by g. On the surface of the Earth, its value is approximately $10\ ms^{-2}$.

For bodies falling down freely g is positive and is negative for bodies moving up.

Galileo was the first scientist to notice that all the freely falling objects have the same acceleration independent of their masses. He dropped various objects of different masses from the leaning tower of Pisa, He found that all of them reach the ground at the same time.

Q40. Write equations of motion for bodies moving under gravity?

Ans: Equations of motion for bodies moving under gravity:

i. $v_f = v_i + gt$

ii. $h = v_i t + \frac{1}{2} gt^2$

iii. $2gh = v_f^2 - v_i^2$

SUMMARY

1. **Rest:** A body is said to be at rest, if it does not change its position with respect to its surroundings.
2. **Motion:** A body is said to be in motion, if it changes its position with respect to its surroundings.
3. Rest and motion are always relative. There is no such thing as absolute rest or absolute motion.
4. Motion can be divided into the following three types.
   Translatory motion: In which a body moves without any rotation.
   Rotatory motion: In which a body spins about its axis.
   Vibratory motion: In which a body moves to and fro about its mean position.
5. **Scalars:** Physical quantities which are completely described by their magnitude only are known as scalars.
6. **Vectors:** Physical quantities which are described by their magnitude and direction are called vectors.
7. **Position:** Position means the location of a certain place or object from a reference point.
8. **Speed:** The distance travelled in any direction by a body in unit time is called speed.
9. **Uniform speed:** If the speed of a body does not change with time then its speed is uniform.
10. **Average speed:** Average speed of a body is the ratio of the total distance covered to the total time taken.
11. **Velocity:** We define velocity as rate of change of displacement or speed in a specific direction.
12. **Average velocity:** Average velocity of a body is defined as the ratio of its net displacement to the total time.
13. **Uniform velocity:** If a body covers equal displacements in equal intervals of time, however small the interval may be, then its velocity is said to be uniform.

14. **Acceleration:** The rate of change of velocity of a body is called acceleration.
15. Uniform acceleration: A body has uniform acceleration if it has equal changes in its velocity in equal interval of time, however small the interval may be.
16. **Graph:** Graph is a pictorial way of describing information as to how various quantities are related to each other.
17. Slope of the distance-time graph gives the speed of the body.
18. **Distance-time graphs:** Distance-time graphs provide useful information about the motion of an object. Slope of the displacement-time graph gives the velocity of the body.
19. Distance covered by a body is equal to area under speed - time graph.
20. Speed-time graph: Speed-time graph is also useful for studying motion along a straight line.
21. **Velocity-time graph:** The distance travelled by a body can also be found from the area under a velocity-time graph if the motion is along a straight line.
22. Equations of motion: Equations of motion for uniformly accelerated motion are:
    - $v_f = vi + at$
    - $S = vi\,t + \frac{1}{2}at^2$
    - $2aS = v_f^2 - v_i^2$
23. **Acceleration due to gravity:** When a body is dropped freely it falls down with an acceleration towards Earth. This acceleration is called acceleration due to gravity and is denoted by *g*. The numerical value of *g* is approximately 10 ms^{-2} near the surface of the Earth.

QUESTIONS

2.1 Encircle the correct answer from the given choices:

i. A body has translatory motion if it moves along a

A. straight line　　B. circle
C. line without rotation　　D. curved path

ii. The motion of a body about an axis is called

A. circular motion　　B. rotatory motion
C. vibratory motion　　D. random motion

iii. Which of the following is a vector quantity?

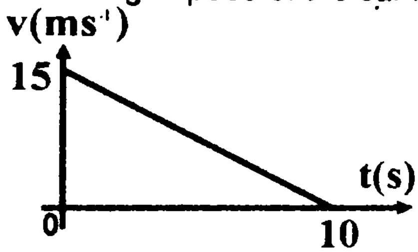
A. speed　　B. distance
C. displacement　　D. power

iv. If an object is moving with constant speed then its distance-time graph will be a straight line.

A. along time-axis　　B. along distance-axis
C. parallel to time-axis　　D. inclined to time-axis

v. **A straight line parallel to time-axis on a distance-time graph tells that the object is**
A. moving with constant speed
B. at rest
C. moving with variable speed
D. in motion

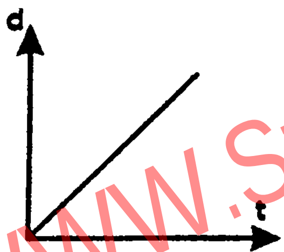
vi. **The speed-time graph of a car is shown in the figure, which of the following statement is true?**
A. car has an acceleration of 1.5 ms^{-2}
B. car has constant speed of 7.5 ms^{-1}
C. distance travelled by the car is 75 m
D. average speed of the car is 15 ms^{-1}



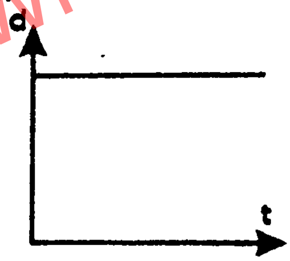
Speed-time graph of a car

vii. **Which one of the following graphs is representing uniform acceleration?**

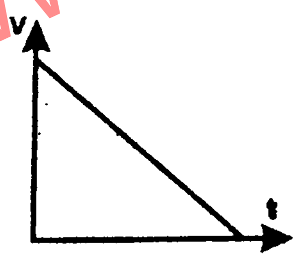
A.



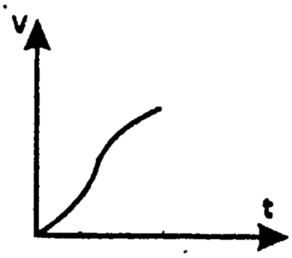
B.



C.



D.



viii. **By dividing displacement of a moving body with time, we obtain**
A. speed
B. acceleration
C. velocity
D. deceleration

ix. **A ball is thrown vertically upward. Its velocity at the highest point is:**
A. - 10 ms^{-1}
B. zero
C. 10 ms^{-2}
D. none of these

x. **A change in position is called:**
A. speed
B. velocity
C. displacement
D. distance

xi. A train is moving at a speed of 36 kmh^{-1}. Its speed expressed in ms^{-1} is:

A. 10 ms^{-1} B. 20 ms^{-1}
C. 25 ms^{-1} D. 30 ms^{-1}

xii. A car starts from rest. It acquires a speed of 25 ms^{-1} after 20 s. The distance moved by the car during this time is:

A. 31.25 m B. 250 m
C. 500 m D. 5000 m

Answers

i. A	**ii. B**	**iii. C**	**iv. D**	**v. B**	**vi. A**
vii. A	**viii. C**	**ix. B**	**x. D**	**xi. A**	**xii. B**

2.2 Explain translatory motion and give examples of various types of translatory motion.

Ans: Translatory motion:

In translational motion, a body moves along a line without any rotation. The line may be straight or curved

Examples:

Riders moving in a Ferris wheel are also in translational motion. Their motion is in a circle without rotation.

Translatory motion of an object along a curved path.

Types of translatory motion:

Translatory motions can be divided into linear motion, circular motion and random motion.

i. Linear motion:

Straight line motion of a body is knows as its linear motion.

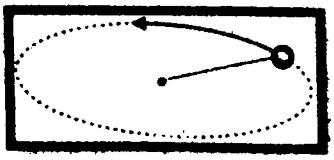
Examples:

The motion of objects such as a car moving on a straight and level road is linear motion.

Aeroplanes flying straight in air and objects falling vertically down are also the examples of linear motion.

ii. Circular motion:

The motion of an object in a circular path is known as circular motion



Examples:

A stone tied at the end of a string can be made to whirl. The stone moves in a circle and thus has circular motion.

Toy train moving on a circular track. A bicycle or a car moving along a circular track possesses circular motion.

Motion of the Earth around the Sun and motion of the moon around the Earth are also the examples of circular motions.

iii. Random motion:

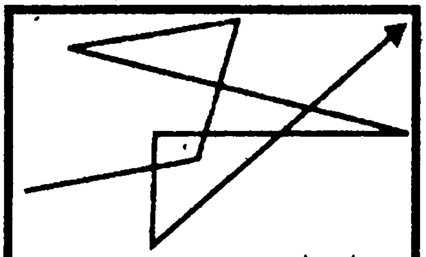
The disordered or irregular motion of an object is called random motion.

Examples:

The motion of insects and birds are irregular. Thus, motion of insects and birds is random motion.

The motion of dust or smoke particles in the air is also random motion.

The Brownian motion of a gas or liquid molecules along a zig-zag path such as shown in figure is also an example of random motion.



Random motion of gas molecules is called Brownian motion

2.3 Differentiate between the following:

(i) Rest and motion.
(ii) Circular motion and rotator motion,
(iii) Distance and displacement
(iv) Speed and velocity,
(v) Linear and random motion,
(vi) Scalars and vectors.

Ans: (i) Rest and motion.

Difference between rest and motion:

Rest:

A body is said to be at rest, if it does not change its position with respect to its surroundings.

Motion:

A body is said to be in motion, if it changes its position with respect to its surroundings.

The state of rest or motion of a body is relative. For example, a passenger sitting in a moving bus is at rest because he/she is not changing his/her position with respect to other passengers or objects in the bus. But to an observer outside the bus the passengers and the objects inside the bus are in motion.

(ii) Difference between circular and rotatory motion:

Any turning as if on an axis is rotary motion. Any rotary motion where the radius of gyration length and axis of rotation are fixed is circular motion. And that's the difference. Circular motion is just a special case of rotary motion. That is, there is no fixed axis and radius restriction for rotary motion, but there is for circular motion.

For example, all planets have rotary motion around their suns. But most of the orbits are elliptical; so the rotation axes (there are two in an ellipse) and radii of

gyration vary as they trek around. So most, if not all, planets do not have circular motion.

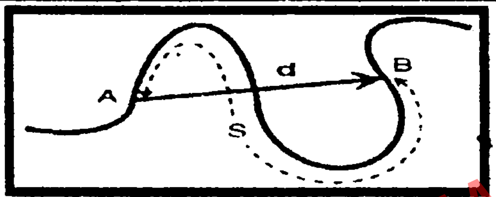
Note:

Gyration length:

A length that represents the distance in a rotating system between the point about which it is rotating and the point to or from which a transfer of energy has the maximum effect.

(iii) Difference between distance and displacement:

Distance	Displacement
i. Length of a path between two points is called the distance between those points.	**i.** Displacement is the shortest distance between two points which has magnitude and direction.
ii. Distance is a scalar quantity.	**ii.** Displacement is a vector quantity.
iii. Distance is denoted by "S". $S = vt$ Its SI unit is metre (m).	**iii.** Displacement is denoted by "**d**". **d** = vt Its SI unit is metre (m).



Distance S (dotted line) and displacement **d** (dark line) from points A to B.

(iv) Difference between speed and velocity:

Speed	Velocity
i. The distance covered an object in unit time is by called its speed. $$Speed = \frac{distance\ covered}{time\ taken}$$ $$Distance = speed \times time$$ or $S = vt$	**i.** The rate of displacement of a body is called its velocity. $$Velocity = \frac{displacement}{time\ taken}$$ $v = \frac{d}{t}$ or $d = vt$
ii. Speed is a scalar quantity.	**ii.** Velocity is a vector quantity.
iii. SI unit of speed is metre per second (ms^{-1}).	**iii.** SI unit of velocity is the same as speed i.e., metre per second (ms^{-1}).

(v) Difference between Linear and random motion,

i. Linear motion:

Straight line motion of a body is knows as its linear motion.

Examples:

The motion of objects such as a car moving on a straight and level road is linear motion.

Aeroplanes flying straight in air and objects falling vertically down are also the examples of linear motion.

iii. Random motion:

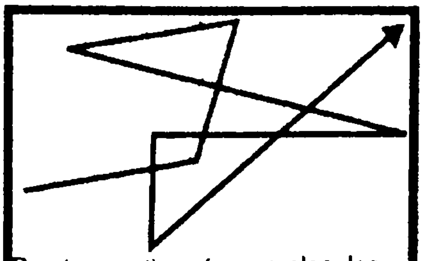
The disordered or irregular motion of an object is called random motion.

Examples:

The motion of insects and birds are irregular. Thus, motion of insects and birds is random motion.

The motion of dust or smoke particles in the air is also random motion.

The Brownian motion of a gas or liquid molecules along a zig-zag path is also an example of random motion.



Random motion of gas molecules is called Brownian motion

(vi) Difference between Scalars and vectors:

Scalars	Vectors
A scalar quantity is described completely by its magnitude only.	A vector quantity is described completely by magnitude and direction.
Examples: Examples of scalars are mass, length, time, speed, volume, work, energy, density, power, electric charge, pressure, area, temperature,	**Examples:** Examples of vectors are velocity, displacement, force, momentum, torque, weight, electric potential, etc.

2.4 Define the terms speed, velocity, and acceleration.

Ans: Speed:

The distance covered an object in unit time is by called its speed.

$$Speed = \frac{distance\ covered}{time\ taken}$$

$$v = \frac{S}{t}$$

Velocity:

The rate of displacement of a body is called its velocity.

$$Velocity = \frac{displacement}{time\ taken}$$

$$v = \frac{d}{t}$$

Acceleration:

Acceleration is defined as the rate of change of velocity of a body.

$$Acceleration = \frac{change\ in\ velocity}{time\ taken}$$

$$Acceleration = \frac{final\ velocity - initial\ velocity}{time\ taken}$$

$$a = \frac{V_f - V_i}{t}$$

Unit of acceleration:

SI unit of acceleration is metre per second per second (ms^{-2}).

2.5 Can a body moving at a constant speed have acceleration?

Ans: Yes, when a body is moving with constant speed, the body can have acceleration if its direction changes. For example, if the body is moving along a

circle with constant speed, it will have acceleration due to the change of direction at every instant.

2.6 How do riders in a Ferris wheel possess translatory motion but not circular motion?

Ans: Riders in a Ferris wheel possess translatory motion because their motion is in a circle without rotation.

2.7 Sketch a distance-time graph for a body starting from rest. How will you determine the speed of a body from this graph?

Ans: Distance-time graph for a body starting from rest:

When a body starting from rest then the distance-time graph is a straight line. Its slope gives the speed of the object.

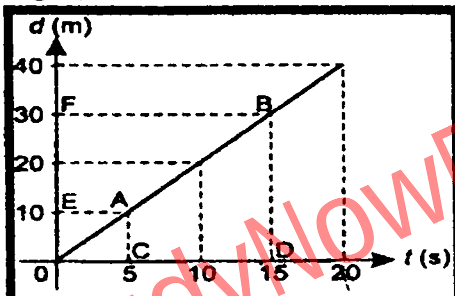
Speed of a body from graph:

Consider two points A and B on the graph.

$$\text{speed of the object} = \text{Slope of line AB}$$

$$= \frac{\text{distance EF}}{\text{time CD}} = \frac{20\,m}{10\,s} = 2\text{ ms}^{-1}$$

The speed found from the graph is $2\ ms^{-1}$.



Distance-time graph showing constant speed

2.8 What would be the shape of a speed - time graph of a body moving with variable speed?

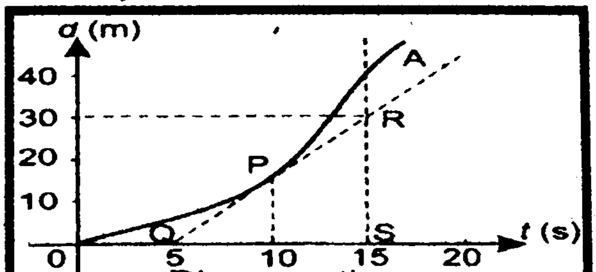
Ans: Object moving with variable speed:

When an object does not cover equal distances in equal intervals of time then its speed is not constant. In this case the distance-time graph is not a straight line.

The slope of the curve at any point can be found from the slope of the tangent at that point. For example,

$$Slope\ of\ tangent\ at\ P = \frac{RS}{QS} = \frac{30\,m}{10\,s} = 3\,ms^{-1}$$

Thus, speed of the object at P is $3\ ms^{-1}$.



Distance-time graph showing variable speed.

Note:

The speed is higher at instants when slope is greater; speed is zero at instants when slope is horizontal.

2.9 Which of the following can be obtained from speed - time graph of a body?

(i) Initial speed.

(ii) Final speed.

(iii) Distance covered in time *t*.

(iv) Acceleration of motion.

Ans: All the given above factors can be obtained from speed-time graph.

2.10 How can vector quantities be represented graphically?

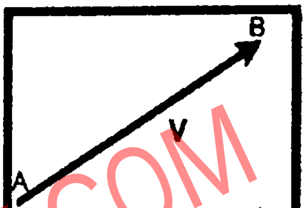
Ans: Representation of vectors (Symbolic representation of a vector):

To differentiate a vector from a scalar quantity, we generally use bold letters to represent vector quantities, such as **F, a, d** or a bar or arrow over their symbols such as $\bar{F}$, $\bar{a}$ $\bar{d}$ or $\vec{F}$, $\vec{a}$ and $\vec{d}$.

Vector representation:

Graphical representation of a vector:

A straight line is drawn with an arrow head at one end. The length of the line, according to some suitable scale, represents the magnitude and the arrow head gives the direction of the vector.



Graphical representation of a vector V

2.11 Why vector quantities cannot be added and subtracted like scalar quantities?

Ans: The scalar quantities obey the rules of arithmetic and ordinary algebra because scalar quantities have no direction. Since vectors have magnitude as well as direction, so vectors obey the special rules of vector algebra therefore vectors are added by head to tail rule (Vector algebra).

2.12 How are vector quantities important to us in our daily life?

Ans: We use vectors in almost every activity of life. A vector is a quantity that has **magnitude** and **direction**.

Examples of everyday activities that involve vectors include:

i. Breathing (your diaphragm muscles exert a **force** that has a magnitude and direction)

ii. Walking (you walk at a **velocity** of around 7 km/h in the direction of the bathroom)

iii. Going to school (the bus has a **length** of about 300 m and is headed towards your school)

iv. Lunch (the **displacement** from your class room to the canteen is about 50 m in a northerly direction)

v. To describe a car's velocity you would have to state it as 80 kmh^{-1} south.

Vectors are important as they describe physical processes in the real world, and without understanding them, we cannot understand how the real world works. Imagine how difficult it would be for an air traffic controller if he didn't understand vectors when directing planes speeds and directions.

2.13 Derive equations of motion for uniformly accelerated rectilinear motion.

Ans: See Q36, Q37 & Q38 from Notes.

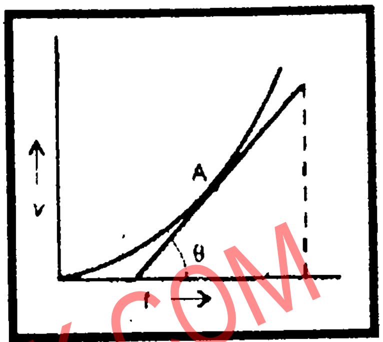
2.14 Sketch a velocity - time graph for the motion of the body. From the graph explaining each step, calculate total distance covered by the body.

Ans: Velocity-time Graph:

Calculation of Distance moved by an object from velocity time graph:

The distance moved by an object can also be determined by using its velocity-time graph.

(a) If object moves at constant velocity **v** for time t. The distance covered by the object. **is** v × t. This distance can also be found by calculating the area under the velocity-time graph. This area is shaded and is equal to v × t.



(b) If the velocity of the object increases uniformly from 0 to **v** in time t. The magnitude of its average velocity is given by

$$V_{av} = \frac{0 + v}{2} = \frac{1}{2}v$$

Distance covered = average velocity × time = $\frac{1}{2}v \times t$

Now we calculate the area under velocity-time graph which is equal to the area of the triangle shaded in Fig. Its value is equal to **1/2 base** × **height = 1/2 v** × **t**

Note: The area between the velocity-time graph and the time axis is numerically equal to the distance covered by the object.

PROBLEMS

2.1 A train moves with a uniform velocity of 36 kmh^{-1} for 10 s. Find the distance travelled by it. (100 m)

Solution: Velocity = v = 36kmh^{-1} = $\frac{36 \times 1000}{60 \times 60\, s}$ = $\frac{36000}{3600}$ = 10ms^{-1}

Time t = 10s

Distance = S = ?

S = vt

S = 10 × 10 = 100m

2.2 A train starts from rest. It moves through 1 km in 100 s with uniform acceleration. What will be its speed at the end of 100 s. (20 ms^{-1})

Solution: Initial velocity v_i = 0 ms^{-1}

Distance S = 1km = 1000 m

Time t = 100 s

Final velocity v_f = ?

$S = v_it + \frac{1}{2}at^2$

$1000 = 0 \times 100 + \frac{1}{2} \times a \times (100)^2$

$1000 = \frac{1}{2} \times 10000a$

$1000 = 5000a$

$a = \frac{1000}{5000} = 0.2\ ms^{-2}$

Now using 1st equation of motion

$v_f = v_i + at$

$v_f = 0 + 0.2 \times 100$

$v_f = 20\ ms^{-1}$

2.3 A car has a velocity of 10 ms^{-1}. It accelerates at 0.2 ms^{-2} for half minute. Find the distance travelled during this time and the final velocity of the car. (390 m, 16 ms^{-1})

Solution: Initial velocity = v_i = 10ms^{-1}

Acceleration a = 0.2ms^{-2}

Time t = 0.5min. = $0.5 \times 60 = 30\,s$

(i) Distance S = ?

(ii) Final velocity v_f = ?

$S = vit + \frac{1}{2}at^2$

$S = 10 \times 30 + \frac{1}{2} \times 0.2 \times (30)^2$

$S = 300 + \frac{1}{2} \times \frac{2}{10} \times 900$

$S = 300 + 90$

$S = 390\ m$

(ii) Using 1st equation of motion

$v_f = v_i + at$

$v_f = 10 + 0.2 \times 30$

$v_f = 10 + 6$

$v_f = 16\ ms^{-1}$

2.4 A tennis ball is hit vertically upward with a velocity of 30 ms^{-1}. It takes 3 s to reach the highest point. Calculate the maximum height reached by the ball. How long it will take to return to ground? (45 m, 6 s)

Solution: Initial velocity = v_i = 30 ms^{-1}

Acceleration due to gravity g = -10 ms^{-2}

Time to reach maximum height = t = 3 s

Final velocity = v_f = 0 ms^{-1}

(i) Maximum height attained by the ball S = ?

(ii) Time taken to return to ground t = ?

$S = vit + \frac{1}{2}gt^2$

$S = 30 \times 3 + \frac{1}{2} \times (-10) \times (3)^2$

$= 90 - \frac{1}{2} \times 10 \times 9$

$= 90 - 45$

$S = 45m$

Total time = Time to reach maximum height + Time to return to the ground

= 3s + 3s = 6s

2.5 A car moves with uniform velocity of 40 ms^{-1} for 5 s. It comes to rest in the next 10 s with uniform deceleration.
Find (i) deceleration (ii) total distance travelled by the car.
($-4\ ms^{-2}$, 400 m)

Solution: Initial velocity = v_i = 40 ms^{-1}
Time = t = 5s
Final velocity = v_f = 0 ms^{-1}
Time t = 10s

(i) Deceleration a = ?
(ii) Total distance S = ?

$v_f = v_i + at$

or $at = v_f - v_i$

$a = \frac{0-40\ ms^{-1}}{10s}$

$a = -4ms^{-1}$

(ii) Total distance travelled = S = $S_1 + S_2$

By using the relation

$S_1 = vt$

$S_1 = 40 \times 5$

$S_1 = 200$ m .... (i)

Now by using 3rd equation of motion

$2aS = v_f^2 - v_i^2$

or $S_2 = \frac{v_f^2 - v_i^2}{2a}$

$S_2 = \frac{(0)^2 - (40)^2}{2 \times (-4)}$

$S_2 = \frac{-1600}{-9}$

$S_2 = 200$ m .... (ii)

From (i) and (ii) we get:

$S = S_1 + S_2$

or $S = 200m + 200m$

$S = 400m$

2.6 A train starts from rest with an acceleration of 0.5 ms^{-2}. Find its speed in kmh^1, when it has moved through 100 m. (36 kmh^{-1})

Solution: Initial velocity v_i = 0 ms^{-1}
Acceleration a = 0.5 ms^{-2}
Distance S = 100 m
Final velocity v_f = ?

$2aS = v_f^2 - v_i^2$

$2 \times 0.5 \times 100 = v_f^2 - 0$

or $100 = v_f^2$

or $v_f^2 = 100$

$v_f = 10ms^{-1}$ .... (i)

Speed in kmh^{-1}:

From (i) we get

$V_f = \frac{10 \times 3600}{1000} = 36\ kmh^{-1}$

2.7 A train staring from rest, accelerates uniformly and attains a velocity 48 kmh^{-1} in 2 minutes. It travels at this speed for 5 minutes. Finally, it moves with uniform retardation and is stopped after 3 minutes. Find the total distance travelled by the train.

Solution: Case-I: **(6000 m)**

Initial velocity = $v_i = 0\ ms^{-1}$

Time = t = 2 minutes = $2 \times 60 = 120\ s$

Final velocity = $v_f = 48\ kmh^{-1} = \frac{48 \times 1000}{3600} = 13.33\ ms^{-1}$

$S_1 = v_{av} \times t$ ....(i)

$S_1 = (\frac{V_f + V_i}{2}) \times t$

$S_1 = \frac{13.333 + 0}{2} \times 120$

$S_1 = 6.6665 \times 120$

$S_1 = 799.99\ m \approx 800\ m$

Case-II:

Uniform velocity = $v_f = 13.333\ ms^{-1}$

Time = t = 5 minutes $5 \times 60 = 300\ s$

$S_2 = v \times t$

$S_2 = 13.333 \times 300$

$S_2 = 3999.9\ m \approx 4000\ m$

Case-III:

Initial velocity = $v_i = 13.333\ ms^{-1}$

Final velocity = $v_f = 0\ ms^{-1}$

Time = t = 3 minutes = $3 \times 60 = 180\ s$

$S_3 = v_{av} \times t$ ....(ii)

$S_3 = (\frac{V_f + V_i}{2}) \times t$

$S_3 = (\frac{0 + 13.333}{2}) \times 180$

$S_3 = 6.6665 \times 180$

$S_3 = 1199.97\ m \approx 1200\ m$

$Total\ distance = S = S_1 + S_2 + S_3$

S = 800 + 4000 + 1200

S = 6000 m

2.8 A cricket ball is hit vertically upwards and returns to ground 6 s later. Calculate

(i) maximum height reached by the ball,

(ii) initial velocity of the ball. **(45 m, 30 ms^{-1})**

Solution: Acceleration due to gravity = $g = -10\ ms^{-2}$ (for upward motion)

Time to reach maximum height (one sided time) = $t = \frac{6}{2} = 3\ s$

Velocity at maximum height = $v_f = 0\ ms^{-1}$

(i) Maximum height reached by the ball S = h = ?

(ii) Maximum initial velocity of the ball v_i = ?

Since, $v_f = vi + gt$

$0 = v_i - (-10) \times 3$

$v_i = 30\ ms^{-1}$

(ii) Now using 3rd equation of motion

$$2aS = v_f^2 - v_i^2$$

$$S = \frac{v_f^2 - v_i^2}{2g}$$

$$S = \frac{(0)^2 - (30)^2}{2 \times (-10)}$$

$$S = \frac{900}{20}$$

$$S = 45 \text{ m}$$

2.9 When brakes are applied, the speed of a train decreases from 96 kmh^{-1} to 48 kmh^{-1} in 800 m. How much further will the train move before coming to rest? (Assuming the retardation to be constant). (266.66 m)

Solution: Initial velocity = v_i = 96 kmh^{-1} = $\frac{96 \times 1000}{60 \times 60} = \frac{96000}{3600}$ ms^{-1}

Final velocity = v_f = 48 kmh^{-1} = $\frac{48 \times 1000}{60 \times 60} = \frac{48000}{3600}$ ms^{-1}

Distance = S = 800 m

Further Distance = S_1 = ?

First of all we will find the value of *acceleration a*

$$2aS = v_f^2 - v_i^2$$

$$2 \times a \times 800 = \left(\frac{48000}{3600}\right)^2 - \left(\frac{96000}{3600}\right)^2$$

$$1600a = \left(\frac{48000}{3600}\right)^2 - \left(\frac{2 \times 48000}{3600}\right)^2 \qquad (\because 96000 = 2 \times 48000)$$

$$1600a = \left(\frac{48000}{3600}\right)^2 \{(1)^2 - (2)^2\} \qquad \left\{Taking \left(\frac{48000}{3600}\right)^2 as\ a\ common\right\}$$

$$1600a = \left(\frac{48000}{3600}\right)^2 \{1 - 4\}$$

$$1600a = \left(\frac{48000}{3600}\right)^2 \{-3\}$$

$$a = -\left(\frac{48000}{3600}\right)^2 \times \frac{3}{1600} \text{ ms}^{-2}$$

Now, we will find the value of further distance S_1:

$v_f = 0$, S_1 = ?

$$2aS = v_f^2 - v_i^2$$

$$-2\left(\frac{48000}{3600}\right)^2 \times \frac{3}{1600} \times S_1 = (0)^2 - \left(\frac{48000}{3600}\right)^2$$

$$S_1 = \left(\frac{48000}{3600}\right)^2 \times \left(\frac{3600}{48000}\right)^2 \times \frac{1600}{3 \times 2}$$

$$S_1 = \frac{1600}{6}$$

$$S_1 = 266.66 \text{ m}$$

2.10 In the above problem, find the time taken by the train to stop after the application of brakes. (80 s)

Solution: By taking data from problem 2.9:

Initial velocity = v_i = 96 kmh^{-1} = $\frac{96 \times 1000}{60 \times 60} = \frac{96000}{3600}$ ms^{-1}

Final velocity = v_f = 0

$$a = -\left(\frac{48000}{3600}\right)^2 \times \frac{3}{1600}\ ms^{-2}$$

Time = t = ?

$$v_f = v_i + at$$

or $at = v_f - v_i$

or $t = \frac{v_f - v_i}{a}$

$$t = \frac{0 - \frac{96000}{3600}}{-\left(\frac{48000}{3600}\right)^2 \times \frac{3}{1600}}$$

$$t = -\frac{96000}{3600} \times -\left(\frac{3600}{48000}\right)^2 \times \frac{1600}{3}$$

$$t = \frac{2 \times 48000}{3600} \times \left(\frac{3600}{48000} \times \frac{3600}{48000}\right) \times \frac{1600}{3}$$

$$t = \frac{2 \times 3600 \times 1600}{4800 \times 3}$$

$$t = \frac{2 \times 3600}{3 \times 3}$$

$$t = 2 \times 40 = 80\ s$$